NASA-CR-192124

137583

p. 24

A Final Report
Grant No. NAGW-2266

August 1, 1990 - May 31, 1991

TECHNICAL NEEDS AND RESEARCH OPPORTUNITIES PROVIDED BY PROJECTED AERONAUTICAL AND SPACE SYSTEMS

Submitted to:

National Aeronautics and Space Administration
Headquarters
600 Independence Avenue, S. W.
Washington, DC 20546

Attention:

Mr. Samuel L. Venneri, Director
Space Research Division

Submitted by:

Ahmed K. Noor
Ferman W. Perry Professor of
Aerospace Structures and Applied Mechanics

Department of Civil Engineering
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA

Report No. UVA/528366/CE92/101
April 1992

Copy No._____

FOREWORD

This is a brief final technical report prepared under NASA Grant NAG-W-2266. It summarizes the work done by the principal investigator, Professor Ahmed K. Noor.

ABSTRACT

The overall goal of the present task is to identify the enabling and supporting technologies for projected aeronautical and space systems. A detailed examination was made of the technical needs in the structures, dynamics and materials areas required for the realization of these systems. Also, the level of integration required with other disciplines was identified. The aeronautical systems considered cover the broad spectrum of rotorcraft; subsonic, supersonic and hypersonic aircraft; extremely high-altitude aircraft; and transatmospheric vehicles. The space systems considered include space transportation systems; spacecrafts for near-earth observation; spacecrafts for planetary and solar exploration; and large space systems. A monograph is being compiled which summarizes the results of this study. The different chapters of the monograph are being written by leading experts from government laboratories, industry and universities.

The principal investigator is Dr. Ahmed K. Noor, Ferman W. Perry Professor of Aerospace Structures and Applied Mechanics, and the NASA Technical Officer for this grant is Mr. Samuel L. Venneri, Director, Space Research Division, NASA Headquarters, Washington, D.C.

SUMMARY OF ACTIVITIES UNDER THE PRESENT GRANT

A brief description of the work done under this grant during the period August 1, 1990 to May 31, 1991, is given subsequently. The specific tasks performed included:

1) compiling a six-volume monograph entitled, "Flight-Vehicle Structures and Dynamics - Assessment and future Directions,"

2) organizing a special session at the 33rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference in Dallas, Texas, April 13-15, 1992. The lead authors highlighted their chapters in this session, and

3) assessing the advances made in computational structures technology and identifying future directions for research in this area.

Summary of the results of this study are included in the proceedings of the SDM Conference (Ref. 1). The highlights of the monograph are included in Appendix A. The list of volumes, chapters and lead authors are included in Appendix B. The aeronautical and space systems considered are included in Appendix C. Two volumes of the monograph (Vols. 3 and 4) are currently being printed by the American Society of Mechanical Engineers. It is anticipated that the remaining four volumes of the monograph will be completed during 1992/1993.

PUBLICATIONS

1. Venneri, S. L. and Noor, A. K., "Overview and Major Characteristics of Future Aeronautical and Space Systems," Proceedings of the AIAA/ASME/ASCE/AHS/ASC 33rd Structures, Structural Dynamics and Materials Conference, April 13-15, 1992, Dallas, Texas, AIAA, Washington, D.C. (to appear).

Highlights of the Monograph on FLIGHT-VEHICLE MATERIALS, STRUCTURES AND DYNAMICS TECHNOLOGIES - ASSESSMENT AND FUTURE DIRECTIONS

edited by Ahmed K. Noor and Samuel L. Venneri

1. Objectives

To review the status and recent major advances in the materials, structures and dynamics technologies; and identify both the technical needs in these areas required to meet the challenges of future aeronautical and space systems as well as the proposed future directions for research.

2. Highlights of the Monograph

- Consists of a number of sections written by leading experts from academia, industry and government labs.
- The monograph will be published by ASME. It will be *typeset*, will *include color illustrations*, will have *a hard cover*, a Library of Congress number, and a very wide distribution.
- The assessment of recent advances will be considerably more detailed than the brief reviews published by Aerospace America in December every year, and the National Academy of Engineering reports.
- Quantitative estimates will be provided whenever possible.
- Extensive list of references will be included at the end of each section.

3. Partial Listing of the Contents

New and Projected Aeronautical and Space Systems

- A detailed list of new and projected aeronautical systems to be built by the U.S., ESA, Japan, and possibly, U.S.S.R. (see tables).
- Includes artists' rendering of some of these systems (in color).

Technical Needs for Future Aeronautical and Space Systems

This includes enabling, and significantly enhancing technologies, divided into disciplinary sections. Clear description is given of the objectives and potential benefits of each item listed.

a) *Materials and Manufacturing Technologies*
- High-performance materials for structural and thermal protection system applications, including:
  - Advanced metallics (e.g., superalloys and intermetallic compounds)
  - Composites (including metal matrix, and advanced carbon-carbon composites)
  - Ceramics (including ceramic-matrix composites)
  - Superconducting technology
- NDE and quality control
- Novel manufacturing and processing techniques (including rapid-solidification-rate (RSR) processing, powder metallurgy, sol-gel techniques and chemical vapor deposition)

b) *Structural Concepts, Fabrication and Repair Techniques*
- New structural concepts (e.g., geometrically efficient concepts, structural tailoring, adaptive (intelligent) structures, convectively cooled structures, and ultralightweight structures)
- New fabrication and joining techniques (e.g., superplastic forming, diffusion bonding, and adhesive bonding)

c) *Structural Dynamics and Control Technology.* This includes:
- Control-structure interaction, including modeling, analysis and design methodology

d) *Loads and Design Criteria*
- Accurate determination of operational loads, including thermal, aerothermal, aerothermoelastic, radiation, dynamic and acoustic loads
- Design procedures and criteria

e) *Analysis and Design Technology (Including Multidisciplinary Analysis and Design)*
- Advanced analysis methods
- Improved life-prediction methods
- Stochastic modeling

f) *Structural Testing and Instrumentation*
- Ground testing of large structural components (static, dynamic, life-cycle and combined loads)
- Flight testing
- Instrumentation for measuring deflections, strains, temperatures and pressures (including on-board electromagnetic and optical sensors for damage detection)

Recent Advances in the Materials, Structures and Dynamics Technologies

Comprehensive review of recent advances, in the last few years in each of the technologies, that can make strong impact on future flight vehicles. The pacing items are included in the future directions for research in the last section.

3.1 *Materials and Manufacturing Technologies*

a) Advanced Metallics
b) Composites
c) Ceramics (Including Ceramic Matrix Composites)
d) NDE and Quality Control

3.2 *Structural Concepts, Fabrication and Joining*

3.3 *Structural Mechanics Including Response Predictions of Structural Components, Failure Mechanisms and Failure Prediction*

3.4 *Structural Dynamics and Control*

3.5 *Aeroelasticity*

3.6 *Loads and Design Criteria for Aeronautical Systems*

3.7 *Loads and Design Criteria for Spacecraft*

3.8 *Interdisciplinary Analysis and Design*

3.9 *Computational Structures Technology*

a) Brief Review of New Computing Systems
b) Material Modeling
c) CSM
d) CAD/CAM
e) Commercial Software and User Experience

3.10 *Structural Testing and Instrumentation*

Future Directions for Research

MONOGRAPH ON FLIGHT-VEHICLE MATERIALS, STRUCTURES AND DYNAMICS - ASSESSMENT AND FUTURE DIRECTIONS

Ahmed K. Noor and Samuel L. Venneri (eds)

List of Volumes and Chapters

Volume 1 - New and Projected Aeronautical and Space Systems, Design Concepts and Loads

Chapter	Lead Authors	Title
1	S. L. Venneri A. K. Noor	New and Projected Aeronautical and Space Systems
2	L. Ascani	Structural Concepts, Fabrication and Joining
3	M.M. Mikulas, Jr. M. Thomson	Large Space Structures
4	J. R. Stephens H. R. Gray	Design Concepts, Fabrication and Joining for Propulsion Systems
5	T. J. Barnes	Loads and Design Criteria for Aircraft
6	E. R. Fleming B. Wada	Spacecraft and Launch Vehicle Loads

Volume 2 - Advanced Metallics, Metal-Matrix and Polymer-Matrix Composites

Chapter	Lead Author	Title
1	E. A. Starke, Jr. D. R. Tenney	Metals and Metal Matrix Composites
2	D. J. Wilkins D. R. Mulville	Fibers, Interfaces and Material Forms
3	M. A. Meador	Polymers and Polymer Matrix Composites

Volume 3 - Ceramics and Ceramic-Matrix Composites

S. R. Levine, Lead Author

Volume 4 - Tribological Materials and NDE

Chapter	Lead Author	Title
1	R. L. Fusaro	Advanced Aerospace Tribological Systems
2	J. D. Achenbach	NDE and Quality Control

Volume 5 - Structural Dynamics and Aeroelasticity

Chapter	Lead Author	Title
1	E. F. Crawley	Structural Dynamics and Controlled Structures Technology
2	T. A. Weisshaar	Aeroelasticity
3	R. J. Allemang D. L. Brown	Structural Dynamics Testing and Instrumentation

Volume 6 - Computational Structures Technology

Chapter	Lead Author	Title
1	A. K. Noor	New Computing Systems and Future Computing Environment
2	S. J. Grisaffe	Computational Materials Science
3	A. K. Noor	Computational Structural Mechanics
4	J. Sobieski	Multidisciplinary Design Optimization

Table 1 - List of future aeronautical systems and some of the associated technical needs in the structures and materials areas.

Class	Goals	Candidate configurations and vehicles	Some of the technical needs
Rotorcraft (Fig. 1)	• To build rotorcraft with increased speed; greater lift; longer range; improved reliability and safety; reduced noise and vibration	a) Next-generation helicopters • single rotor • tandem rotor • advancing blade concept • conventional compound b) Advanced high-speed rotorcraft • tilt rotor • folding tilt rotor • tilt prop • tilt wing • stoppable rotors • body-mounted rotors • variable-diameter rotors c) Large-passenger/cargo helicopters	• New rotor concepts and advanced transmissions • Advanced composite materials and manufacturing techniques • Design/analysis capability for low vibrations and low noise • Nondestructive testing and evaluation • Structural tailoring
Subsonic aircraft (Fig. 2)	• To build fuel-efficient, affordable aircraft operating in a modernized national airspace system • To build low-cost highly maneuverable ground attack military aircraft	• Commercial transport • Short-medium range (propfan) • Long range (turbofan or propfan) • Commuter aircraft • Military transport • short haul • long haul • assault • subsonic strike aircraft • Single engine • short/medium range	• Advanced materials and structural concepts • plastic and metal matrix composites • aluminum-lithium alloys • superplastic forming • rapid solidification technology (RST) • diffusion-bonded titanium sandwich construction • Advanced joining concepts and adhesive bonding • Sensors for on-board fault detection • Testing for unconventional and hard to inspect structures • Design for low detection by visual, audible and electronic methods

Table 1 - Continued

Class	Goals	Candidate configurations and vehicles	Some of the technical needs
Supersonic aircraft (Fig. 3)	• To attain long distance efficiency • To build highly maneuverable and effective military fighter and attack aircraft	• High-speed commercial transports (HSCT) • Advanced tactical fighter (AFT) • Supersonic short takeoff-vertical landing aircraft (STOVL) • Short/medium range single or twin engine	• Metal-matrix, carbon/carbon and impact-toughened composites • Rapid solidification alloys (e.g.,Al/Ti) and ceramics • Advanced structures for propulsion • System incl. airframe/propulsion integration • Aeroservoelasticity • Highly-integrated computer controlled flight controls • Design configuration and materials processors for very low detection by visual and electronic methods • Smart integrated structures combining embedded sensors for health monitoring; and/or antenna capabilities
Hypersonic aircraft and missiles	To develop manned and unmanned hypersonic vehicles to operate in the sensible atmosphere at Mach 5-12 (these include long-range • To build low-cost highly maneuverable ground attack military aircraft	• Commercial hypersonic transport • Military penetrator aircraft concept • Military hypersonic accelerator vehicle • Hypersonic airbreathing missile	• Metal-matrix, ceramic-matrix and carbon/carbon composites • Airframe/propulsion integration • Advanced programmable controls • Convectively cooled structural concepts • Cryogenic tanks • Low heat transfer, structurally reliable joining methods

Table 1 - Continued

Class	Goals	Candidate configurations and vehicles	Some of the technical needs
Hypersonic aircraft and missiles (Cont'd.)			• Design concepts and materials for cryogenic fuels containment • Passive or active thermoprotection methods for cryogenic fuels
Extremely high-altitude aircraft missiles	To conduct long-endurance missions at high altitudes (60,000-100,000 + ft) at speeds 300 knots or less. Missions include communication relay; earth-resource monitoring; atmospheric sampling; surveillance	• Solar-powered aircraft • Microwave-powered aircraft • Combustible fuel aircraft • Blimp	• Ultra-lightweight structures • Long-endurance and lightweight propulsion energy storage systems

Hypersonic/ aerospace craft and orbiters (Fig. 4)	To provide a capability for routine cruising and maneuver into and out of atmosphere with takeoff and landing from conventional runways (exploiting the growing convergence of aeronautics and space technology)	• Hypersonic aerospacecraft
		  • NASP X-30 demonstrator (U.S.)
		  • HYTEX demonstrator (Germany)
		• Orbiters of single-stage-to-orbit vehicles (SSTO)
		  • NASP X-30 demonstrator (U.S.)
		  • STS-2000 (France)
		  • Unmanned orbiter - Interim Hotol (Britian)
		• Orbiters of two-stage-to-orbit vehicles (TSTO)
		• Manned and unmanned versions of Sänger (Germany)
		• Manned Gliderplane - Hermes (France-ESA)
		• Unmanned Glider - Hope (H-2 Orbiting PlanE - Japan)
		• Large shuttle - Buran (Russia)
			• High-temperature ceramic superconductors
			• Lightweight and high strength thermostructural design concepts
			• Durable, reusable thermal protection system
			• Advanced metal-matrix composite materials
			• Highly integrated airframe/ propulsion system (blended engine/airframe)
			• Cryogenic fuel containment
			• Actively-cooled structural concepts
			• Aeroservoelasticity

Table 2 - List of some of the major space systems

Category	Vehicles
Space transportation systems (Fig. 5)	a) *Launch vehicles* • Orbit-on-demand vehicle for deployment, space station visit, repair/service, retrieve/rescue, and observation • Personnel launch system (PLS) • Advanced manned launch system (AMLS) • Heavy lift launch vehicle (HLLV) • Japanese H-I and H-II • French Ariane-5 Launcher • Russian Energia and SL-16 b) *Service vehicles* • Upper stage vehicle • Orbital maneuvering vehicle (OMV). For local transportation between space station and its outlying cooperating elements c) *Reusable, two-way long-range space transportation systems* • Orbital transfer vehicle (OTV) for transportation between LEO and GEO • Cargo transfer vehicle (CTV) • Translunar orbital transfer vehicle for transportation to lunar base • Mars transfer vehicle • Assemblies of OTV for launching payloads into trajectories for solar system exploration and manned mission to planets
Spacecrafts, vehicles and space systems for missions and observation of near-earth environment (Fig. 6)	• Earth probes • Extreme ultraviolet explorer (EUVE) • Advanced x-ray astrophysics facility (AXAF) • Space infrared telescope facility (SIRTF) • X-ray timing explorer (XTE) • Submillimeter wave astronomy satellite (SWAS) • Far ultraviolet spectroscopy explorer (FUSE) • Interferometric observatory • Gravity probe-B (GP-B) • Lunar transit telescope (LTT)
Spacecraft for solar system exploration	a) *Missions for Inner Planets* • Solar probe • Lunar observer • Lunar rover/sample return • Mars network/probe • Mars rover/sample return • Mercury orbiter b) *Missions for Outer Planets and other solar systems* • Titan (largest moon of Saturn) (CASSINI Mission) • Comet rendezvous/astroid flyby (CRAF) • Pluto flyby/Neptune orbiter • Grand tour cluster • Interstellar probe

Table 2 - Continued

Category	Vehicles
Large space systems and space station (Figs. 6, 7)	• Space station Freedom (SSF) • Earth orbiting systems (EOS) (polar and geostationary platforms) • Advanced tracking and data relay satellite system (ATDRSS) • Large deployable reflector (LDR)
Outposts and habitats (Fig. 8)	• Lunar outpost transportation system and surface systems • Mars outpost transportation system and surface systems

Notes: 1) Low Earth Orbits (LEO) are those just beyond the Earth's atmosphere.
2) Geostationary (geosynchronous) orbit (22,300 miles above the Earth's equator) is the orbit in which spacecraft match the Earth's 24-hour rotation and hold fixed longitudes.

A92-3 ... 92

OVERVIEW AND MAJOR CHARACTERISTICS OF FUTURE AERONAUTICAL AND SPACE SYSTEMS

Samuel L. Venneri and Ahmed K. Noor

AIAA Paper No. 92-2441

To be presented at the

AIAA/ASME/ASCE/AHS/ASC 33rd Structures, Structural Dynamics and Materials Conference
April 13-15, 1992
Dallas, Texas

OVERVIEW AND MAJOR CHARACTERISTICS OF FUTURE AERONAUTICAL AND SPACE SYSTEMS

Samuel L. Venneri* and Ahmed K. Noor**

Introduction

Design and performance requirements for future flight vehicles are going through sweeping changes today primarily due to ambitious objectives of the U.S. civil and military aerospace programs, as well as the aerospace programs of the European community, Japan, and the former Soviet republics. In aeronautics, future goals include higher cruising speeds, altitudes and thrust-to-weight ratios. The technology drivers for future aircraft include reduction in material, fabrication and maintenance costs; reduction in weight; extended life; higher operating temperature; and signature reduction. In space future goals include lower transportation cost to space; long-duration space flights; planetary missions; and extraterrestrial bases. The key design requirements for future space vehicles include low-launch weight, small structural distortion, long-term environmental stability and survivability from external hostile threats.

Many of the significant technology breakthroughs in the aeronautics and space fields have either resulted from, or critically depended on breakthroughs in the materials, structures and dynamics technologies. The realization of planned and future aeronautical and space systems requires the proper integration of the technology advances in the materials, structures and structural dynamics disciplines, as well as in other disciplines including aerodynamics, propulsion, controls, avionics, optics, electromagnetics and acoustics.

Some of the new and projected aeronautical and space systems are described in this paper. The major characteristics of these systems are given in Ref. 1. The major advances in the materials, structures and dynamics areas required for the realization of these systems are given in Ref. 2. Herein, only a brief summary of the future systems and their characteristics and technical needs is given.

Future Aeronautical Systems

Future aeronautical systems include: rotorcraft, subsonic, supersonic, hypersonic and extremely high-altitude aircraft. Some of the candidate configurations and vehicles in each category are listed in Table 1 along with a brief summary of the technical needs for the realization of these systems. Several national technology programs are currently underway in support of these systems. These include High-Speed Civil Transport (HSCT); National Aerospace Plane (NASP); Advanced Tactical Fighter (ATF); Integrated High-Performance Turbine Engine Technology (IHPTET); and Advanced Composite Technology (ACT) Program.

Future Space Systems

The new and projected space systems include the space station and extensions such as orbital factory, the space transportation systems (earth-to-orbit vehicles, orbit maneuvering and orbit transfer vehicles), spacecraft used for manned and unmanned observation of near-earth environment, astronomy missions, exploration of the planets of the solar system, exploration of comets and asteroids, and permanent lunar and martian bases. National technology programs in support of these systems include National Launch System (NLS), Space Defense Initiative (SDI), Space Exploration Initiative (SEI) which includes both Lunar and Mars program elements; and Controls Structures Interaction (CSI) Program.

Comments on Future Systems and Their Characteristics

Some of the systems listed in Tables 1 and 2 have already passed the conceptual stage and are in the testing stage; others have just been conceptualized. Artists' drawings of some of the future vehicles are shown in Figs. 1 through 8. The contrast between the goals of a current supersonic commercial airliner (Concorde) and those of future HSCT is given in Fig. 9. The specific strengths of advanced material systems at different Mach numbers and different temperatures are shown in Fig. 10. The characteristics of HSCT engine are shown in Fig. 11.

Some of the proposed vehicles show a merging of former vehicle definitions. For example, the tiltrotor vehicles take off and hover like a rotorcraft but fly at high subsonic speed like a fixed-wing airplane. The folding tilt rotor concept proposed by Boeing (Fig. 1) has a forward swept wing (like the X-29) which requires structural tailoring to control wing pitch-bending response. Hypersonic aerospacecraft will combine horizontal takeoff and landing capability with that of routine cruising and maneuver into and out of atmosphere.

For high-speed aircraft the relative size of the propulsion system to that of the aircraft increases rapidly with the increase in flight Mach number. The same trend is observed for the relative magnitude of the forces generated by the propulsion system to those of the aerodynamic forces. For hypersonic airbreathing vehicles mutual interactions between these forces are advantageous

*Director, Space Research Division, NASA Headquarters, Washington, D.C.
**Professor of Aerospace Structures and Applied Mechanics, and Director, Center for Computational Structures Technology, University of Virginia, Fellow AIAA.

when the propulsion system is properly integrated with the vehicle airframe. Therefore, in order to obtain optimum overall performance all the current hypersonic aerospacecraft concepts are based on integrating the propulsion system with the vehicle airframe.

Design requirements for future launch vehicles include increased reliability, reduced cost, and improved launch on-time performance. This, in turn, requires low-cost, low-risk engines, lightweight, low-cost structures and materials, fault-tolerant avionics and increased automation in the ground and launch operations.

Future platforms include earth orbiting platforms, space station, and deep space platforms. Precision requirements mandate the integration of controls and structures disciplines into a multidisciplinary technology, controls structure Interaction - CSI, to enable the accurate prediction of in-space behavior and maximize the performance of large flexible space structures.

Design drivers for future spacecraft include low launchweight, small structural distortions and extended space durability and environmental stability.

The planet surface systems currently considered in the space exploration initiative, SEI, include human and habitation systems; surface vehicles; central power and communication systems; launch and landing systems, extravehicular mobility unit and robotics. Radiation protection and shielding concepts need to be developed for these systems.

<u>Brief discussion of the technical needs in the materials, structures and dynamics areas</u>

Advances in materials, structures, dynamics, and manufacturing technologies will play a dominant role in the design and development of future aeronautical and space systems. In addition, the realization of these systems requires proper integration of technology advances in a number of other disciplines including propulsion, aerodynamics, controls, avionics, optics, electromagnetics, and acoustics. Detailed discussions of these technology needs are given in the different chapters of a new monograph (Ref. 2).

The following is a brief summary of some of the technical needs for future systems.

1. High-performance materials, novel processing methods, and advanced structural concepts to achieve significant weight reductions, improved performance, higher operating temperatures, longer lives, and/or lower costs. The high-performance materials include advanced metallics (e.g. aluminum-lithium alloys, rapid-solidification-rate (RSR) metals); high-temperature composites (e.g. ceramic composites, carbon-carbon composites, thermoplastics, advanced metal-matrix and hybrid composites). Engineered materials highlighted in the succeeding section can significantly improve the performance and reduce the cost of future systems. The processing methods include rapid solidification, powder metallurgy, sol-gel techniques, and chemical vapor deposition.

Novel processing methods also include superplastic forming and diffusion-bonding concepts, and advanced joining concepts such as adhesive bonding. The structural concepts include structural tailoring of composites to achieve high levels of performance which cannot be achieved by traditional materials, adaptive structures, and active cooling for hypersonic vehicles (see Fig. 12). Adaptive structures are described in the succeeding section.

The new aluminum-lithium alloys offer weight reduction and stiffness improvements. Rapid-solidification-rate metals and carbon-carbon composites have the potential of operating at very high temperatures while retaining the properties of usability and long life. Superplastic forming and diffusion-bonded titanium sandwich construction is promising for laminar flow control. Advanced joining concepts have the potential of reducing manufacturing costs as well as allowing novel, geometrically efficient concepts.

2. Very high precision shaped and controlled space structures subjected to dynamic and thermal loads. The benefits of using CSI technology for these structures are depicted in Fig. 13.

3. Efficient structural systems for spacecraft subjected to very high accelerations.

4. Improved orbital delivery systems, emphasizing larger payloads, lower cost, and high reliability.

5. Innovative techniques for packaging,, deploying, assembling, and fabricating very large space structures, including the use of robotics. Of particular importance are the methods of joining members of flexible structures and techniques for artificially stiffening these structures.

6. Design criteria and improved techniques for the accurate determination of operational loads. This is particularly true for the future high-performance aircraft and large, flexible space structures.

7. An increasingly higher level of integration of technical disciplines is required to achieve significant improvement in vehicle performance, safety and economy. Examples are provided by the structures/thermal/propulsion/ controls integration of supersonic and hypersonic aircraft and the structures/thermal/controls/optics integration for large flexible space vehicles.

8. Development and use of electromagnetic and optical sensors for onboard fault-testing of unconventional and hard-to-inspect structural components.

9. Improved design of structural details such as joints, damping, vibration isolation and suppression mechanisms. This is particularly true for future rotorcraft and for turboprop engines.

10. Improved life prediction methods and thermal management techniques for structural components subject to very high temperatures.

11. Radiation protection and shielding concepts for planet surface systems and transfer vehicles

Engineered Materials and Adaptive Structures Concepts

Performance breakthroughs for future flight vehicles are likely to result from the use of engineered materials and adaptive structures concepts which are highlighted subsequently.

Engineered Materials

The central paradigm of the engineered materials (or material-by-design) philosophy is the sequential interrelation of processing, structure, properties and performance of materials. Ideally, the inner structure of the material is used to predict properties, then the properties are used to predict performance, and finally, a sequence of processing procedures are selected to yield the desired material and inner structure at a reasonable cost.

An important element in the material-by-design activity is the development of a hierarchy of material models for describing the phenomena associated with different material properties. The disciplines involved include computational chemistry (which covers both molecular dynamics and quantum mechanics); computational material science; and computational structural mechanics.

Smart/Adaptive Structures

The smart/adaptive structure concept refers to the integration and coordination of sensing and actuating capabilities in the structure through information processing software. Smart/adaptive structures have capabilities for sensing and responding to external stimuli imposed upon them. Such structures may also be able to identify and assess damage, and take appropriate action to repair it, or isolate the damaged part without impairing the normal functioning of the structure. Performance improvements resulting from smart/adaptive structures concept are possible at four different levels:

• Process control to tailor the material properties for specific application - embedded sensors can sense temperature, strain and even chemical reactions during material processing and alert processors when temperature (and pressure) adjustments are needed.

• Quality testing (nondestructive evaluation).

• Vehicle health monitoring. This is accomplished by sensing, strain, vibration, impact damage, fracture, fatigue, wear, thereby assessing the integrity of the vehicle and guarding against catastrophic damage.

• Flight control, including flight path control, vibration suppression and shape control of the vehicle for optimum performance throughout the flight envelope. The concept has high potential for a broad spectrum of vehicles including rotorcrafts, subsonic aircraft, high-speed civil transport, and large flexible spacecraft. It is likely to change the way flight vehicles are designed, built, maintained and flown.

References

1. Venneri, S. L. and Noor, A. K., "Overview and Major Characteristics of Future Aeronautical and Space Systems," Chapter 1, Vol. 1 in Monograph Series on *Flight Vehicle Materials, Structures and Dynamics Technologies - Assessment and Future Direction*, Noor, A. K. and Venneri, S. L. (eds.), ASME, New York, 1992.

2. Noor, A. K. and Venneri, S. L. (eds.), Monograph Series on *Flight Vehicle Materials, Structures and Dynamics Technologies - Assessment and Future Direction*, Vol. 1, New and Projected Aeronautical and Space Systems, Design Concepts and Loads, Vol. 2, Advanced Metallics, Metal-Matrix and Polymer Matrix Composites,Vol. 3, Ceramics and Ceramic Matrix Composites,Vol. 4. Tribological Materials and NDE,Vol. 5, Structural Dynamics and Aeroelasticity, Vol. 6, Computational Structures Technology, ASME, New York, 1992.

Table 1 - List of future aeronautical systems and some of the associated technical needs in the materials, structures and dynamics areas.

Class	Goals	Candidate configurations and vehicles	Some of the technical needs
Rotorcraft (Fig. 1)	• To build rotorcraft with increased speed; greater lift; longer range; improved reliability and safety; reduced noise and vibration	a) Next-generation helicopters • single rotor • tandem rotor • advancing blade concept • conventional compound b) Advanced high-speed rotorcraft • tiltrotor • canard tiltrotor • folding tiltrotor • variable-diameter tiltrotor • tilt prop • tilt wing • stoppable rotors • body-mounted rotors c) Large-passenger/cargo helicopters	• New rotor concepts and advanced transmissions • Advanced composite materials and manufacturing techniques • Design/analysis capability for low vibrations and low noise • Nondestructive testing and evaluation • Structural tailoring
Subsonic aircraft (Fig. 2)	• To build fuel-efficient, affordable aircraft operating in a modernized national airspace system • To build low-cost highly maneuverable ground attack military aircraft	• Commercial transport • Short-medium range (propfan) • Long range (turbofan or propfan) • Commuter aircraft • Military transport • short haul • long haul • assault • subsonic strike aircraft • Short/medium range single engine	• Advanced materials and structural concepts • polymer and metal matrix composites • aluminum-lithium alloys • superplastic forming • rapid solidification technology (RST) • diffusion-bonded titanium sandwich construction • Advanced joining concepts and adhesive bonding • Sensors for on-board fault detection • Testing for unconventional and hard to inspect structures • Design for low detection by visual, audible and electronic methods
Supersonic aircraft (Fig. 3)	• To attain long distance efficiency • To build highly maneuverable and effective military fighter and attack aircraft	• High-speed commercial transports (HSCT) • Advanced tactical fighter (ATF) • Supersonic short takeoff-vertical landing aircraft (STOVL) • Short/medium range single or twin engine	• Metal-matrix, carbon/carbon and impact-toughened composites • Rapid solidification alloys (e.g.,Al/Ti) and ceramics • Advanced structures for propulsion • System integration including airframe/propulsion • Aeroservoelasticity • Highly-integrated computer controlled flight controls • Design configuration and materials processors for very low detection by visual and electronic methods • Smart integrated structures combining embedded sensors for health monitoring; and/or antenna capabilities

Table 1 - Continued

Class	Goals	Candidate configurations and vehicles	Some of the technical needs
Hyper-sonic aircraft and missiles	• To develop manned and unmanned hypersonic vehicles to operate in the sensible atmosphere at Mach 5-12 (these include long-range • To build low-cost highly maneuverable ground attack military aircraft	• Commercial hypersonic transport • Military penetrator aircraft concept • Military hypersonic accelerator vehicle • Hypersonic airbreating missile	• Metal-matrix, ceramic-matrix and carbon/carbon composites • Airframe/propulsion integration • Advanced programmable controls • Convectively cooled structural concepts • Cryogenic tanks • Low heat transfer, structurally reliable joining methods • Design concepts and materials for cryogenic fuels containment • Passive or active thermoprotection methods for cryogenic fuels
Extremely high-altitude aircraft missiles	To conduct long-endurance missions at high altitudes (60,000-100,000 + ft) at speeds 300 knots or less. Missions include communication relay; earth-resource monitoring; atmospheric sampling; surveillance	• Solar-powered aircraft • Microwave-powered aircraft • Combustible fuel aircraft • Blimp	• Ultra-lightweight structures • Long-endurance and lightweight propulsion energy storage systems
Hypersonic/ aerospace craft and orbiters (Fig. 4)	To provide a capability for routine cruising and maneuver into and out of atmosphere with take-off and landing from conventional runways (exploiting the growing convergence of aeronautics and space technology)	• <u>Hypersonic aerospacecraft</u> • NASP X-30 demonstrator (U.S.) • HYTEX demonstrator (Germany) • <u>Orbiters of single-stage-to-orbit vehicles</u> (SSTO) • NASP X-30 demonstrator (U.S.) • STS-2000 (France) • Unmanned orbiter - Interim Hotol (Britian) • <u>Orbiters of two-stage-to-orbit vehicles</u> (TSTO) • Manned and unmanned versions of Sänger (Germany) • Manned Gliderplane - Hermes (France-ESA) • Unmanned Glider - Hope (H-2 Orbiting PlanE - Japan) • Large shuttle - Buran (Russia)	• High-temperature ceramic superconductors • Advanced metal-matrix composite materials • Lightweight and high strength thermostructural design concepts • Durable, reusable thermal protection system • Highly integrated airframe/ propulsion system (blended engine/airframe) • Cryogenic fuel containment • Actively-cooled structural concepts • Aeroservoelasticity

Table 2 - List of some of the future space systems

Category	Vehicles
Space transportation systems (Fig. 5)	a) *Launch vehicles* • Advanced manned launch system (AMLS) • Heavy lift launch vehicle (HLLV) • Orbit-on-demand vehicle for deployment, space station visit, repair/service, retrieve/rescue, and observation • Japanese H-I and H-II • French Ariane-5 Launcher • Russian Energia and SL-16 b) *Service vehicles* • Upper stage vehicle • Orbital maneuvering vehicle (OMV). For local transportation between space station and its outlying cooperating elements • Personnel launch system (PLS) c) *Reusable, two-way long-range space transportation systems* • Orbital transfer vehicle (OTV) for transportation between LEO and GEO • Cargo transfer vehicle (CTV) • Lunar transfer vehicle • Lunar excursion vehicle (piloted and cargo) • Mars transfer vehicle • Mars excursion vehicle (piloted and cargo) • Assemblies of OTV for launching payloads into trajectories for solar system exploration and manned mission to planets
Spacecrafts, vehicles and space systems for missions and observation of near-earth environment (Fig. 6)	• Earth probes • Extreme ultraviolet explorer (EUVE) • Advanced x-ray astrophysics facility (AXAF) • Space infrared telescope facility (SIRTF) • X-ray timing explorer (XTE) • Submillimeter wave astronomy satellite (SWAS) • Far ultraviolet spectroscopy explorer (FUSE) • Interferometric observatory • Gravity probe-B (GP-B) • Lunar transit telescope (LTT)
Spacecraft for solar system exploration	a) *Missions for Inner Planets* • Solar probe • Lunar observer • Lunar rover/sample return • Mars network/probe • Mars rover/sample return • Mercury orbiter b) *Missions for Outer Planets and other solar systems* • Titan (largest moon of Saturn) (CASSINI Mission) • Comet rendezvous/astroid flyby (CRAF) • Pluto flyby/Neptune orbiter • Grand tour cluster • Interstellar probe

Table 2 - Continued

Category	Vehicles
Large space systems and space station (Figs. 6, 7)	• Space station Freedom (SSF) • Earth orbiting systems (EOS) (polar and geostationary platforms) • Advanced tracking and data relay satellite system (ATDRSS) • Large deployable reflector (LDR)
Outposts and habitats (Fig. 8)	• Lunar outpost transportation system and surface systems • Mars outpost transportation system and surface systems

Notes: 1) Low Earth Orbits (LEO) are those just beyond the Earth's atmosphere.
2) Geostationary (geosynchronous) orbit (22,300 miles above the Earth's equator) is the orbit in which spacecraft match the Earth's 24-hour rotation and hold fixed longitudes.

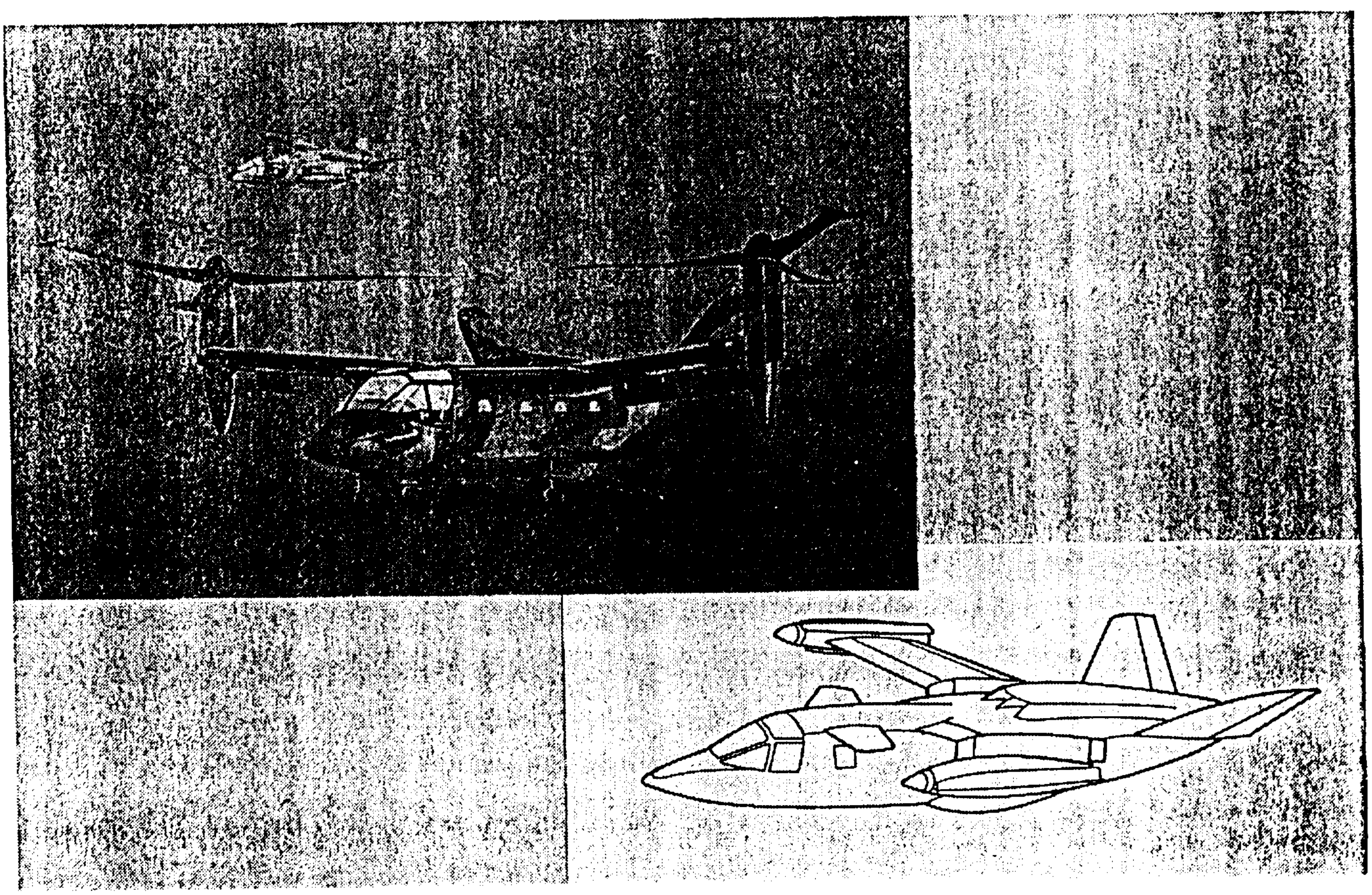
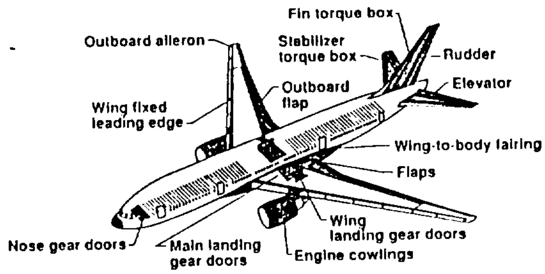
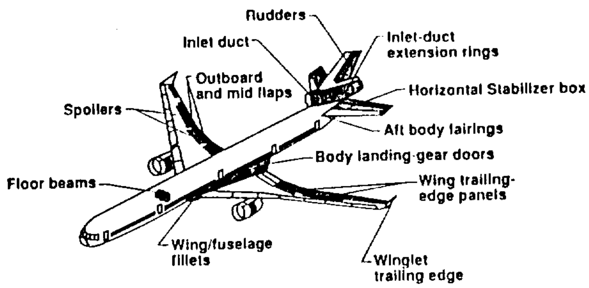


Figure 1 - High-speed rotorcraft concept (folding tiltrotor - Boeing).



BOEING 777



MC DONNELL DOUGLAS MD-12X

Figure 2 - Future subsonic aircraft - composite parts are shaded.

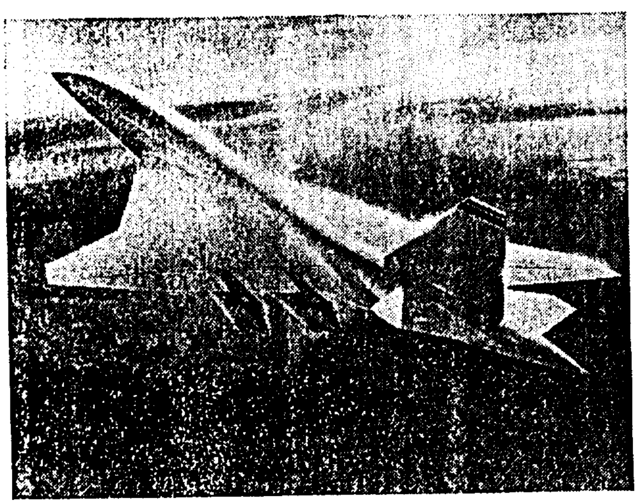
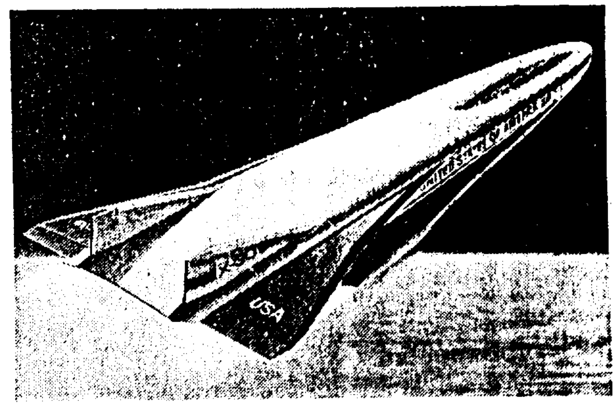
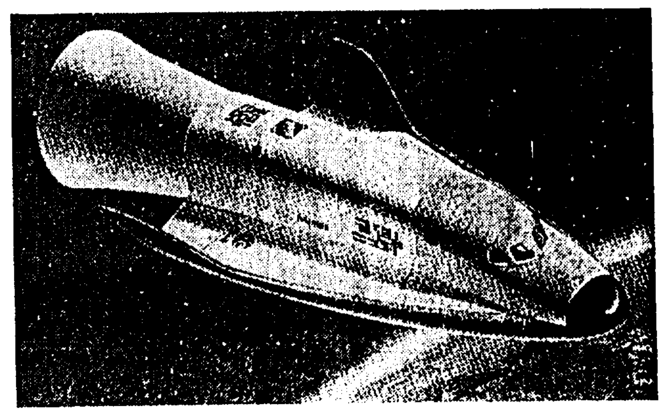


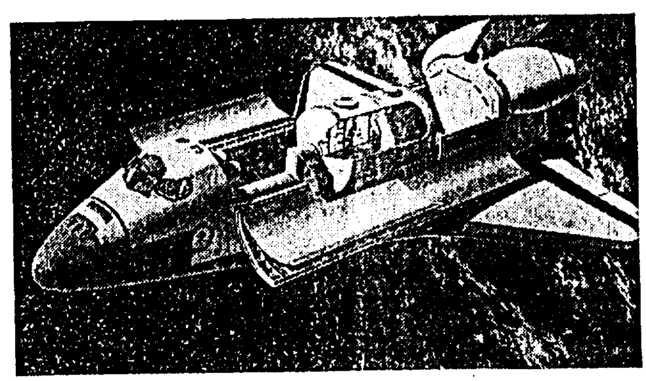
Figure 3 - Mach 2.5 HSCT concept.



NASP X-30 (U.S.)



Hermes (France - ESA)



HOPE (H-2 Orbiting PlanE - Japan)

Figure 4 - Aerospace planes and orbiters.

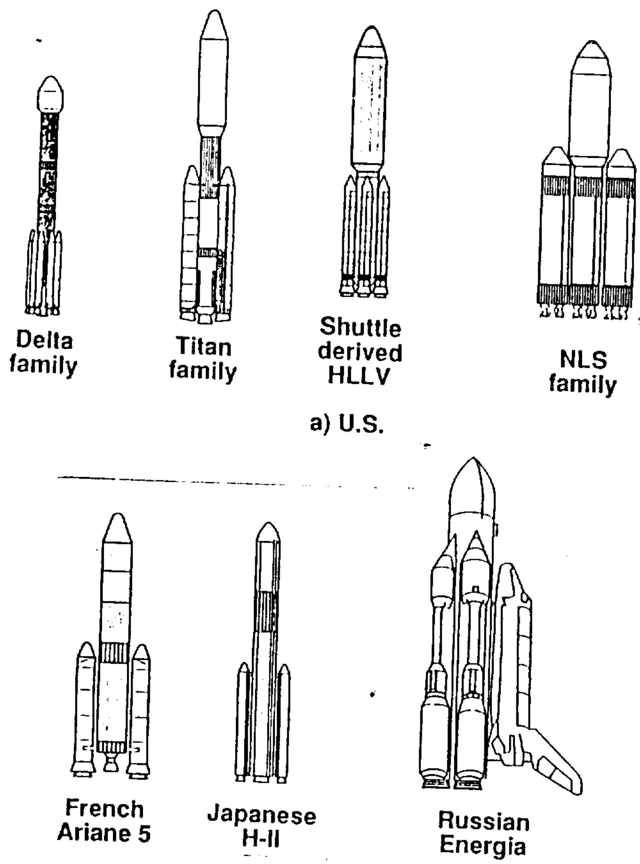


Figure 5 - Launch vehicles.

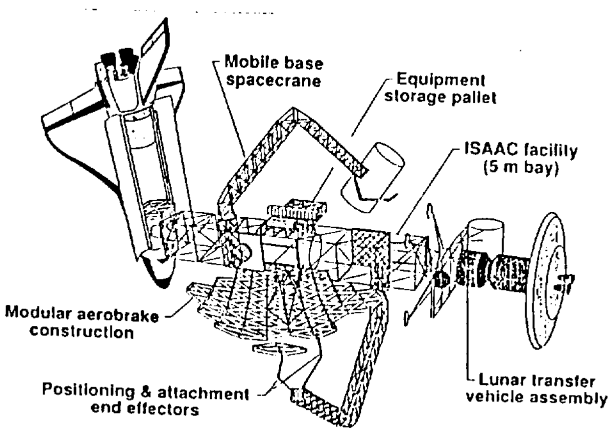
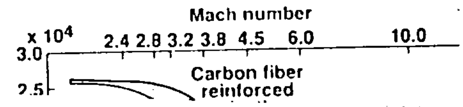
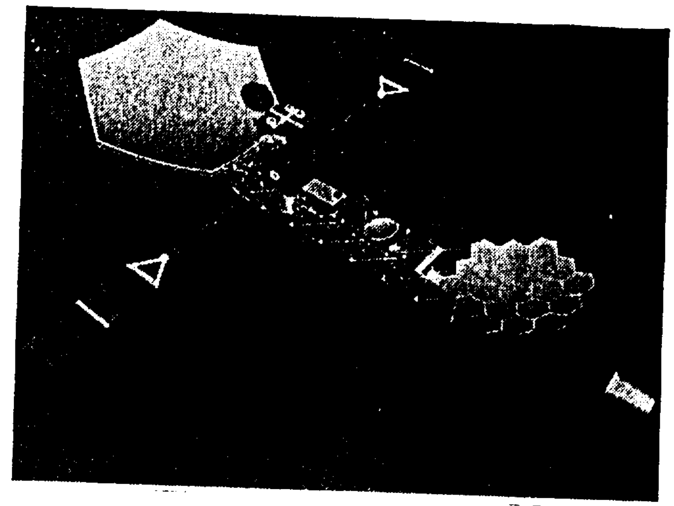
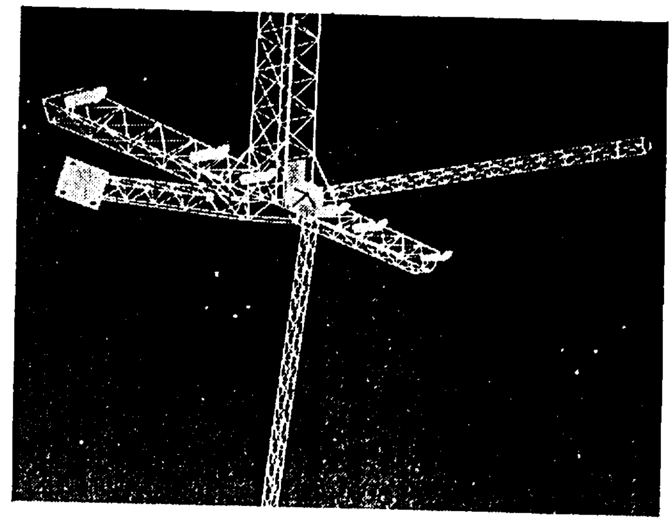


Figure 6 - EOS-geostationary platform and space-based optical interferometer.



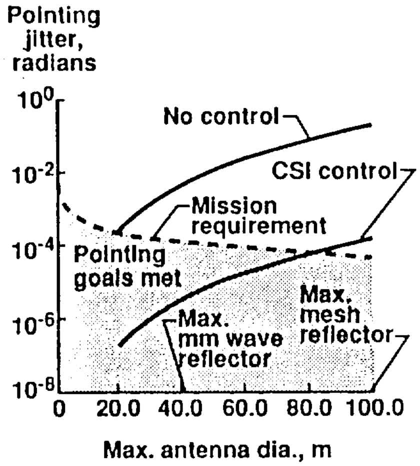


EOS - Geostationary Platform

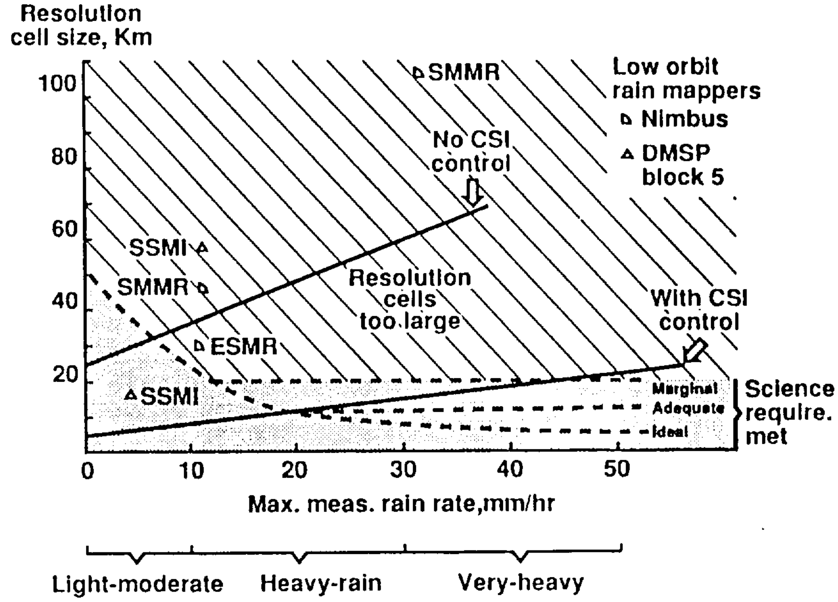


Space-based optical interferometer

Figure 7 - In-space assembly and construction facility concept.



a) Pointing performance



b) Precipitation measurement capability

Figure 13 - CSI technology benefits.

DISTRIBUTION LIST

1 - 3*	National Aeronautics and Space Administration Headquarters 600 Independence Avenue, S. W. Washington, DC 20546 Attention: Mr. Samuel L. Venneri, Director Space Research Division	
**	National Aeronautics and Space Administration Headquarters/Contracts and Grants Division Code HWB-1 600 Independence Avenue, S. W. Washington, DC 20546 Attention: Melvin E. Tyson Closeout Administrator	
4 - 5*	National Aeronautics and Space Administration Scientific and Technical Information Facility P. O. Box 8757 Baltimore/Washington International Airport Baltimore, MD 21240	
**	SEAS Postaward Administration	
6 - 7	A. K. Noor	
8	F. W. Barton	
9 - 10	E. H. Pancake	
11	SEAS Preaward Administration Files	

*One unbound original
**Cover letter.

JO#4388:ph